Groundwater Heat Pump with Pumping and Recharging in the Same Well in China

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Abstract: In China, a new-style groundwater heat pump emerged in 2000. In this system, the production well and the injection well is integrated into one well, which is divided into three parts by clapboards: a low pressure (production) space, a seals section, and a high pressure (injection) space. In contrast to a conventional groundwater heat pump, this new-style groundwater heat pump is named the Groundwater Heat Pump with Pumping and Recharging in the Same Well (GWHPPRSW). Up to now, over 180 projects have been established with a total construction area exceeding 2,500,000 m^2. The well structure of GWHPPRSW is depicted. The advantages and disadvantages of the GWHPPRSW are analyzed. The differences between the Pumping & Recharging Well (PRW) and Standing Column Well (SCW) are compared in detail. Potential problems and applicability ranges are pointed out. The investigation on operational status of 11 different types of buildings equipped GWHPPRSW carried out by Beijing Municipal Bureau of Statistics shows that the mean operation cost per heating area of GWHPPRSW is lower than that of municipal central heating. GWHPPRSW has low initial investment, operates economically and is friendly to the environment. It is especially well suited to places with appropriate hydrogeological conditions and those with groundwater permission from the local government.

Key words: groundwater heat pump; standing column well; pumping & recharging in the same well; characteristic; China

1. INTRODUCTION

Groundwater heat pump (GWHP) is a branch of ground source heat pump (GSHP)[1]. It was installed firstly in 1948 at Commonwealth Building, Portland, Oregon, USA[2, 3], which was paid extensive attention from the beginning of design[4-6]. In the following decades, its applications have been widely carried out [3, 7]. Until 1999, over 100 projects had been installed with a total heating area about 1,000,000 m^2 in Shandong, Hunan, Hubei, Liaoning, Heilongjiang, Beijing, Hebei and et al in China[8]. The research on GWHP is also promoted by wide applications. Some new systems and well frames are put forward. In China, a new-style groundwater heat pump was invented in the end of 2000. In this system, the production well and the injection well are integrated in one well. Pumping and injection work simultaneously at the same plane spot but different depth of aquifer[9]. This new-style groundwater heat pump is named Groundwater Heat Pump with Pumping & Recharging in the Same Well (GWHPPRSW) different from conventional groundwater heat pump (GWHPPRDW) which has two wells at least with pumping and recharging in the different wells[10]. In 2001, GWHPPRSW was adopted firstly on some project in Beijing. After its success, GWHPPRSW is being popularized and applied quickly. Upon to now, over 180 projects have been installed with a total construction area about 2,500,000 m^2[11], including small villas with construction area only 200 m^2 and large buildings with construction area exceeding 120,000 m^2. And building types include not only common buildings, such as hotels, residential buildings, shopping centers, office buildings, schools and gymnasiums, but also special buildings, such as hospitals, archives and factories, landscape buildings (such as China national Theatre), etc. The region of applications has extended from Beijing to Shanghai, Tianjing, Hebei, Heilongjiang, Shanxi, Shandong, Sichuan, and some remote provinces (such as Qinghai, Tibet and Sinkiang), etc[12].

2. PRINCIPLE AND CHARACTERISTICS

A schematic of Pumping & Recharging Well (PRW) of GWHPPRSW is showed in Fig. 1. PRW combines the production well and injection well into one, which is divided into three parts by clapboards: low pressure (production) space in the low part of the well, seal section in the middle part and high pressure (injection) space in the top part. When the submersible pump is running, groundwater is sent to heat exchanger at the wellhead, where it releases heat, and then is sent back to the injection space through the same well, serving as low-grade heat source of heat pump and providing low-grade heat to heat pump. The existence of the middle seal section is to alleviate the mixture of injection water and production water. Therefore, the above-mentioned technology is also called “Single Well System of Supplying and Returning Water” technology in somewhere.

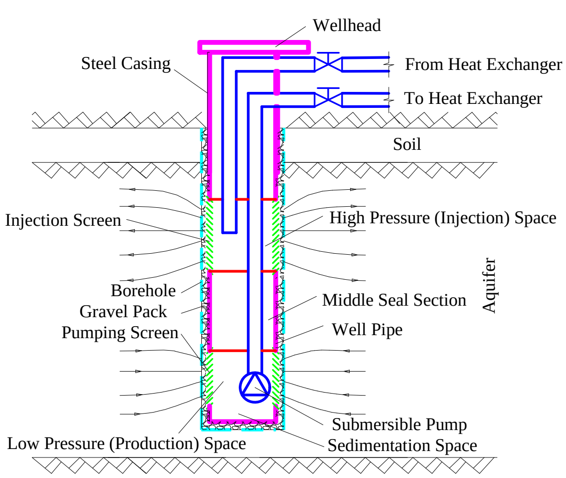

Fig.1 Schematic of pumping & recharging well

Generally speaking, PRW has following characteristics:

(1) The low-grade heat source of GWHP is groundwater. The temperature of groundwater fluctuates little all the year round. Therefore, the Heating Seasonal Performance Factor (HSPF) and Energy Efficiency Ratio (EER) of the unit are high. Compared with air-source heat pump (ASHP), GWHP can save 23-44 % power energy[13], and reduce peak electric demand[14], especially in winter, which has positive effect to balance the on and off-peak electric load of the power grid. The two tests of GWHP in 1980s showed that the efficiency and the output of GWHP were not affected by outdoor air temperature[15] and was increase with the fall of outdoor air temperature[16]. GWHPPRSW, as one type of GWHP, holds the above advantages of GWHP.

(2) Compared with conventional GWHP, GWHPPRSW reduces the number of wells and area of the plot and saves the first cost accordingly. The initial investment of GWHPPRSW is only 1/4-1/3 of the conventional geothermal heating systems[17, 18].

(3) The groundwater quality is not influenced by the operation of GWHPPRSW. Water Source Monitoring Center of Beijing Municipality continuously monitored the groundwater quality (21 index properties) in the inner well and around aquifer of several projects in the last three years. The results showed that none of the indexes had significant changes except the temperature of groundwater. It completely indicates that GWHPPRSW does not affect the quality of groundwater except the temperature of groundwater[10].

(4) Pumping and injection occur simultaneously at the same plane spot but different depth of aquifer. The relative negative pressure of pumping is helpful to injection.

(5) On the other hand, injection water flows into the pumping space through seepage ineluctably for the difference of groundwater pressure, which could cause the thermal breakthrough of a certain extent. Accordingly, the temperature of pumping water could change along with the running of GWHPPRSW[19]. From point of view of heat transfer, thermal breakthrough is the key point, which determines the success or failure of GWHPPRSW. The rapid and tremendous change of pumping water temperature is not permitted for the water source heat pump and the groundwater itself. It can decrease the efficiency of

the unit and even freeze the groundwater.

(6) The low-grade heat source of GWHPPRSW is groundwater, different from that of GCHP. Specific volume heat capacity of groundwater is 2-3 times larger than that of soil. Forced convection heat transfer and thermal dispersion are caused by groundwater seepage during the operation of GWHPPRSW. Therefore, the heat exchange of groundwater is more furious than that of soil with conduction, and the thermal effective range is farther. As a result, single PRW can burden larger load.

(7) The number of PRWs, well frame parameters, distance between wells as well as operation behavior need to be designed specifically according to the given geological conditions because of the complexity and variability of the geological conditions. It makes the design of GWHPPRSW relatively complicated.

3. COMPARE PRW WITH STANDING COLUMN WELL

Standing Column Well (SCW) was first developed in the mid 1970s. During the 1990s, the SCW was promoted by the Association of Energy Energizers (AEE) and ASHRAE. And the commercial market came into its own[20]. The SCW in now recognized by ASHRAE; ISPHA taught the SCW for the first time in 2003 in the certified design course[21]. Now, there are approximately 1000 SCW installations in the United States. Most of them are located in the Northeast and Pacific Northwest in addition to parts of Canada in heating-dominated residential and light commercial applications[20, 22]. These regions have suitable hydrological and geological conditions.

Fig. 2 shows the schematic of standing column well. As showed in Fig. 2, SCW can be regarded as a transfiguration of the coaxial heat exchanger of ground-coupled heat pump (GCHP). It cuts down the outside pipe of the coaxial pipe in competent bedrock, and lets fluid circulate directly in borehole to exchange heat with rock of borehole[20, 23]. The SCW is sometimes referred to as semi-open loop systems [24]. When SCW is applied in residential buildings at geologic regions with good groundwater quality, sometimes it also serves to provide household domestic water. The submersible pump is placed at the top or bottom of the borehole according to the depth of the well. In residential applications, the submersible pump is usually placed at the bottom of the borehole for the well is shallower. However, larger commercial / industrial applications may require placing the submersible pump at the top of borehole and connecting the submersible pump to a perforated intake tube inserted to the bottom of the borehole for the larger scale of the system and deeper well[25].

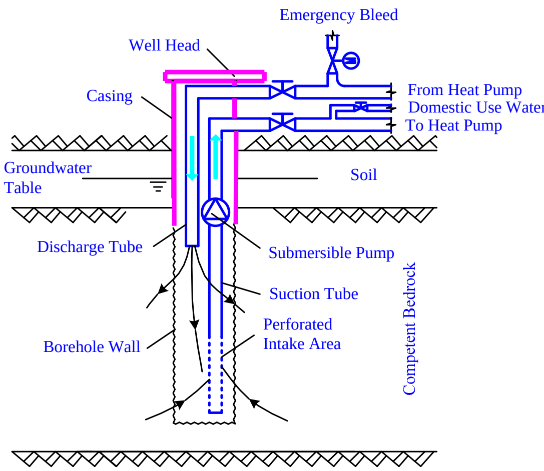

Fig. 2 Schematic of standing column well

The SCW has many advantages compared to other ground heat exchangers of closed-loop ground-coupled systems[26].

(1) The heat transfer between the circulating water and the well bore in SCW is improved by eliminating the conductive resistance of the outer plastic pipe and the contact thermal resistance between the pipe and the well bore.

(2) Compared to the U-tube heat exchanger in a 150mm back-filled hole, SCW has larger heat transfer area because the diameter of U-tube is only 40mm.

(3) The uncased borehole’s surface in SCW is always rougher than the surface of plastic pipe. The roughness increases the borehole’s surface area and causes local turbulence, which enhances the heat transfer from SCW.

(4) More importantly, the induced interaction

between the circulating water and the groundwater through the uncased borehole has the potential to improve the system performance dramatically.

During peak temperature periods, SCW can bleed some water from the system to induce groundwater flow[20]. The bleed strategies is a key parameter in system design and operation[22]. The bleed groundwater can drain to the earth some distance away or return to a separate return well. The common rate of bleed is 10 % of system flow. And 2/3 SCWs have some bleed activity during the winter season[25]. Bleed serves the following purposes[20]:

(1) Reduces the required well depth for a given load condition and consequently reduces initial costs.

(2) Improves energy consumption by moderating the fluid temperatures and increasing the efficiency of the heat pump.

(3) Avoids freezing in the SCW during winter season.

The borehole depth per kW heat pump capacity of SCW reduces enormously compared to ground-coupled heat pump just for the improvement of heat transfer[25]. Tab. 1 gives the compare of borehole length, first cost and 20-year life-cycle cost of SCW with no groundwater bleed with that of common types of ground-coupled closed-loop heat exchangers, such as single U-tube, double U-tube and concentric tube under the same load and geology conditions[24]. Tab. 1 show that SCW with no bleed requires much smaller borehole length, first cost and life-cycle cost than other ground heat exchangers. Furthermore, SCW with 10 % emergency bleeds can reduce 50 % of borehole length compared with SCW with no bleed, therefore, the significant reduction of capital cost is achieved[21].

Compared with SCW, PRW has well pipe and clapboards in the well pipe in order to alleviate the thermal breakthrough of injection and pumping water. SCW lets fluid circulate directly in borehole, and has no problem of injection clogging, though has strong thermal breakthrough. Although SCW is a type of heat exchanger belonging to groundwater heat pump [22], without groundwater, it can work normally. Thus, there is no need of test wells and extensive hydrogeological investigation, which simplifies the design and saves the primary cost[23]. SCW needs to be installed in competent bedrock in order to avoid collapsing. SCW consists of a borehole that is cased until competent bedrock is reached. The New York State Department of Mineral Resources (DMR) requires that the well casing be driven 21.5 meters into competent bedrock. Upon indication of solid and unfractured rock the DMR has agreed upon a reduction of that depth to as low as 11 meters[23]. The remaining depth of the well is then self-supporting through bedrock. Because the casing needs to be driven into competent bedrock, it is not economical when the bedrock is excess deep. If existence of groundwater, it may cause metal to corrode when groundwater of poor quality enters system. Therefore, SCW is feasible in the region where the competent bedrock is available and very near to the ground surface and the quality of groundwater is good[25, 27].

However, the applied location of PRW must have aquifers with suitable buried depth and excellent ability of reinjection, and can provide moderate quantity and quality groundwater. Usually, in order to avoid inferior quality groundwater corroding heat pump, the plate heat exchanger is installed to separate the groundwater loop from heat pump. The borehole of typical SCW has a nominal diameter of 150 mm and depth ranging from150m to 460 m[24]. The ideal distance of boreholes is 15-23 m. The cooling capacity of one SCW of 460 m in depth is 105-140 kW[23]. A typical PRW has a borehole of 800 mm in diameter and 85 m in depth, well pipe of 500 mm in diameter and production & injection pipe of 100 mm in nominal diameter. When circulation rate of groundwater is 100 t/h, the capacity of low-grade heat is 580 kW[10].

4. THE ANALYSIS OF POWER CONSUMPTION AND COST IN WINTER

The operation data of the heating season from 11 different types of buildings installed GWHPPRSW in Beijing is analyzed by Beijing Municipal Bureau of Statistics. These samples are Building of Haidian District Administration (BHDA), Building of Haidian

District Court (BHDC), Building of Zhongguancun Information Center (BZIC), Second Building of Haidian District Administration (SBHDA), Building of Haidian District Police Bureau (BHDPB), Business Building Complex of Haidian District (BBCHD), Songlu Hotel (SH), Jintaige Residential Buildings (JRB), Beijing Haidian Foreign Language School (BHFLS), Baianju Shopping Center (BSC) and Oushang Shopping Center (OSC), respectively. The types of the buildings are various, e.g. office building, business building, residential building, hotel building, school building and shopping center building. Data is monitored during the governed heating period, from 2003-11-12 to 2004-03-17, total 126 days. The general situation of 11 buildings is showed in Tab. 2.

The electric energy consumption (EEC) and cost per heating area are showed in Fig. 3 and Fig. 4. As showed in Figures, total EEC per heating area and heating EEC per heating area are different from each other for the different building types and properties. The ranges of total EEC and EEC of heating per heating area are 14.3-53.1 kWh/m^2 and 14.2-42.5kWh/m^2, and its mean values corresponding to area are 35.5kWH/m^2 and 31.2kWh/m^2, respectively. The heating cost per heating area is RMB 9.48-28.85 Yuan/m^2 and its mean value corresponding to area is RMB 17.39 Yuan/m^2, which is slightly higher than the minimum price of coal fired heating, RMB 16.5 Yuan/m^2, governed by Beijing Price Bureau in 2001, lower than that of municipal central heating, RMB 24-30 Yuan/m^2 and greatly lower than that of heating fired oil, gas or electricity, RMB 30-35 Yuan/m^2. Among 11 buildings, specific area heating cost of 7 buildings, which accounts for 70% investigated buildings, is lower than the minimum price of coal fired heating. And all buildings' specific area heating cost is lower than that of heating fired oil, gas or electricity. That is to say, the application of GWHPPRSW in Beijing is very economical not only

Tab. 1 Summary of borehole length and first cost as well as 20-year life-cycle cost of ground-coupled closed-loop heat exchangers and SCW with no bleed

	Single U-tube	Double U-tube	Concentric Tube	SCW with no bleed
Borehole length	1	0.78	0.67	0.64
First cost	1	0.84	0.90	0.59
20-year life-cycle cost	1	0.90	0.92	0.76

Tab. 2 The general situation of 11 buildings

No.	Name	Building Property	Construction Area (m^2)	Heating Area (m^2)	Role of System
1	BHDA	Energy-Saving Building	57000	57000	Heating, Cooling, Domestic Hot Water, Fresh Air
2	BHDC	Energy-Saving Building	28978	21000	Heating, Cooling, Domestic Hot Water, Fresh Air
3	BZIC	Energy-Saving Building	20000	17000	Heating, Cooling, Fresh Air
4	SBHDA	Energy-Saving Building	63000	31000	Heating, Cooling, Fresh Air
5	BHDPB	Energy-Saving Building	33744	33744	Heating, Cooling, Domestic Hot Water, Fresh Air
6	BBCHD	Energy-Saving Building	82400	30000	Heating, Cooling, Fresh Air
7	SH	Non-Energy-Saving Building	10400	10400	Heating, Cooling, Domestic Hot Water
8	JRB	Energy-Saving Building	14130	14130	Heating, Cooling, Domestic Hot Water
9	BHFLS	Non-Energy-Saving Building	65308	65308	Heating, Cooling, Domestic Hot Water
10	BSC	Energy-Saving Building	22044	22044	Heating, Cooling, Domestic Hot Water, Fresh Air
11	OSC	Energy-Saving Building	22000	22000	Heating, Cooling, Domestic Hot Water, Fresh Air

Note: All buildings except buildings No. 3, 10 and 11 installed the on and off-peak electric energy meter.

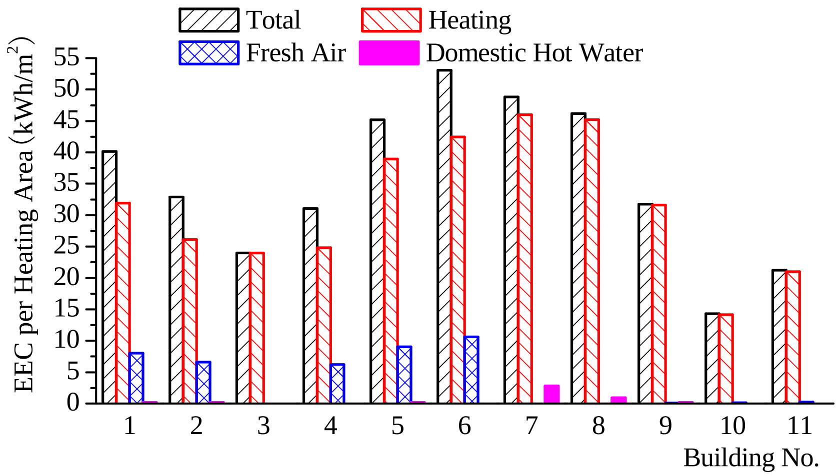

Fig.3 EEC per heating area of 11 buildings

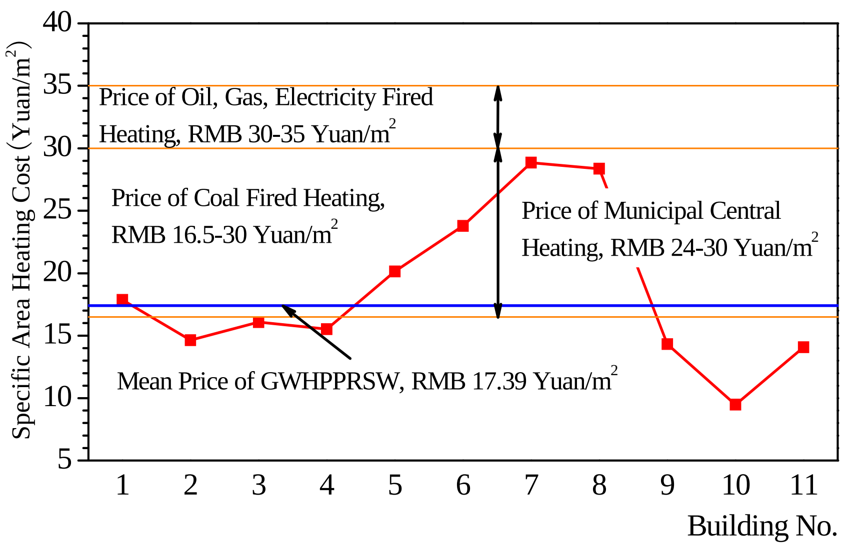

Fig.4 Heating cost per heating area of 11 buildings

in power consumption, but also in operation cost. This also is the reason that GWHPPRSW attracts so much attention of users and government agencies in China.

5. CONCLUSIONS

GWHPPRSW is a new-style GWHP which is invented in China. In this system, the production well and the injection well are integrated in one well. This new-style groundwater heat pump is named Groundwater Heat Pump with Pumping & Recharging in the Same Well (GWHPPRSW) different from conventional groundwater heat pump (GWHPPRDW) which has two wells least with pumping & recharging in different wells. Up to now, over 180 projects have been established with a total construction area exceeding 2,500,000 m^2. The investigation on operation status of 11 different types of buildings with GWHPPRSW implemented by Beijing Municipal Bureau of Statistics shows that the mean operation cost per construction area is lower than that of municipal central heating. Compared with traditional heating techniques, GWHPPRSW has low initial investment, operates economically and is friendly to environment. It is especially well suited to the places with appropriate hydrogeological condition and groundwater permission by local government.

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